APPLICATION

of

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for

UNITED STATES LETTERS PATENT

on

DEPLOYABLE STRUCTURES

Docket No. ELLAC-73328

Sheets of Drawing Figures: 7

Express Mail Label No. EV 740511939 US

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10/570910
IAP20 Rec'd PCT/PTO 03 MAR 2006

DEPLOYABLE STRUCTURES

FIELD OF INVENTION

The present invention relates broadly to deployable structures and an assembly comprising a plurality of deployable structures.

BACKGROUND

Deployable structures, for example, space frames, beam structures, etc., are required in a wide variety of applications. These structures are usually transported in a folded state to a chosen site for deployment. After use, they may be folded back and stored for redeployment.

In general, conventional deployable structures suffer from poor structural configurations in a fully deployed state. Many conventional foldable structures deploy into non-optimal shapes as the requirement for the structure to be foldable imposes geometric constraints that are sometimes contrary to structural requirements. Further, the deployable structures may be bulky in a folded state, and are mechanically complex in design.

Typical self-stabilizing or "clicking" or "self-locking" deployable structures do not provide structurally optimal forms in the fully deployed state. Some of them require enormous forces and coordination for deployment and undergo significant bending during deployment. Other forms of structural systems require a large number of individual components and complicated assembly operations to form the structure, making deployment or folding the structures time consuming and costly.

SUMMARY

In accordance with a first aspect of the present invention there is provided a deployable structure comprising:

a plurality of pairs of hingeably connected members,

a first hinge element; and

a second hinge element;

wherein the two members of each pair of hingeably connected members are connected to the first and the second hinge elements respectively; and

wherein the first hinge element is capable of being stabilized for facilitating stabilization of the deployable structure into a deployed state.

The deployable structure may further comprise:

a central member wherein the first and second hinge elements are connected to different ends of the central member; and

wherein one portion of the first hinge element is detachably connected to the central member such that the first hinge element is stabilized when connected to the central member.

The deployable structure may further comprise a fastening element to fasten the first hinge element to the central member.

The deployable structure may comprise three or more pairs of hingeably connected members.

One of the two members in each pair of hingeably connected members may be connected to the other member of said pair by at least one third hinge element.

The deployable structure may further comprise cables or flexible elements connecting the third hinge elements.

One of the two members in each pair of hingeably connected members may connected to the other member of said pair via one or more secondary members.

The secondary members may be substantially parallel to an imaginary line joining the first and second hinge elements, when the deployable structure is in the deployed state.

The hinge elements may allow a single degree-of-freedom of movement.

The members may comprise one or more of a group comprising struts, rods, tubes, telescopic elements, self stabilizing elements and cables.

The deployable structure may further comprise one or more energy stored devices for facilitating deployment and/or folding of the deployable structure.

In accordance with a second aspect of the present invention there is provided an assembly comprising a plurality of deployable structures, each deployable structure comprising:

a plurality of pairs of hingeably connected members,

a first hinge element; and

a second hinge element;

wherein the two members of each pair of hingeably connected members are connected to the first and the second hinge element respectively; and

wherein the first hinge element is capable of being stabilized for facilitating stabilizing the deployable structure in a deployed state.

Each deployable structure may further comprise:

a central member wherein the first and second hinge elements are connected to different ends of the central member; and

wherein one portion of the first hinge element is detachably connected to the central member such that the first hinge element is stabilized when connected to the central member.

The assembly may further comprise at least one cable or connecting the plurality of deployable structures.

The at least one cable or may connect hinge elements of the plurality of deployable structures.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the invention will be better understood and readily apparent to one of ordinary skill in the art from the following written description, by way of example only, and in conjunction with the drawings, in which:

Figure 1 is a schematic representation of a deployable structure according to an embodiment of the present invention;

Figure 2 is a schematic representation of the deployable structure of Figure 1 when partially folded;

Figure 3a is a schematic representation of a plurality of connected deployable structures according to another embodiment of the present invention;

Figure 3b is a schematic representation of a plurality of connected deployable structures according to another embodiment of the present invention;

Figure 4 a is a schematic representation of a plurality of connected deployable structures according to another embodiment of the present invention;

Figure 4b is a schematic representation of a plurality of connected deployable structures according to another embodiment of the present invention;

Figure 4c is a schematic representation of a plurality of connected deployable structures according to another embodiment of the present invention;

Figure 5 is a schematic representation of the deployable structure Figure 1, showing an upper plane, a middle plane and a lower plane;

Figure 6 is a schematic representation of a structural unit according to another embodiment of the present invention;

Figure 7 is a schematic representation of a structural unit according to yet another embodiment of the present invention;

Figure 8 is a schematic representation of a structural unit according to another embodiment of the present invention;

Figure 9 is a schematic representation of a structural unit according to yet another embodiment of the present invention;

Figure 10 is a schematic representation of a structural unit according to another embodiment of the present invention

DETAILED DESCRIPTION

Generally, the described embodiments relate to a structural system of foldable, deployable or collapsible structures made up of interconnected units that are extensible and collapsible into various structural shapes, for example, space frames, panels, columns, domes, vaults.

A schematic representation of a deployable structure 100 in an example embodiment is shown in Figure 1. In this embodiment, the deployable structure 100 comprises a central element 130, four upper elements 140, four lower elements 150, and a network of cables or flexible elements 170. In this embodiment, the upper and lower elements 140, 150 are struts. However, it should be appreciated that the upper and lower elements may be in the form of rods, tubes, cables, etc, or a combination of different elements. The four lower elements 150 are attached to a lower hinge 104, and the four upper elements 140 are attached to an upper hinge 108. Each of the upper elements 140 is hingeably connected to a corresponding lower element 150 by a middle hinge 112, forming a pair. Each middle hinge 112 is connected to adjacent middle hinges 112 by the network of cables 170. The upper and lower elements 140, 150 may be made of metallic or composite materials.

The hinges 104, 108, 112 allow the upper and lower elements 140, 150 to rotate in a single degree-of-freedom, acting as pin-joints, and enable deployment and folding of the deployable structure 100.

When the deployable structure 100 is in a deployed state, one end of a central element 130 is detachably connected to the upper elements 140 via the upper hinge 108, and the other end of the central element 130 is connected to the lower elements 150 via the lower hinge 104. This allows the deployable structure100 to be folded or deployed by attaching or detaching the end of the central element 130 from the upper hinge 108. It should be appreciated that the central element 130 may be detachably connected to either the lower hinge 104 or the upper hinge 108 at one end or both ends. Alternatively, the central element 130 may comprise two sections (not shown) detachably joined with each end of the central element 130 attached to the upper hinge 108 and the lower hinge 104, respectively. The upper hinge 108 may have means for disengaging and engaging the detachable end of the central element 130, for example, a fastening mechanism (not shown) may be used to lock the detachable end of the central element 130 to the upper hinge 108 when the deployable structure 100 is fully deployed.

When the deployable structure 100 is in an upright, deployed state as shown in Figure 1, the central element 130 is substantially perpendicular to the ground 190.

The deployable structure 100 in Figure 1 is in the form of a square module. However, it should be appreciated that numerous other configurations, for example, triangular, hexagonal, pentagonal or other polygonal shapes may be formed with substantially the same arrangement, which has the central element 130 connecting the lower and upper hinges 104, 108.

The basic unit shown in Figure 1 can also be implemented without the central member by restraining the geometry of the upper elements (140) and lower elements 150 by means of a lockable hinges 108, 112, 104, which restrain the movement of the elements 140, 150 when the deployable structure 100 is in the fully deployed state.

In another example embodiment, upper hinges 1080 may be disposed between lower hinges 1040 and a network of cables or flexible members 1700 joining the middle hinges 1120, as shown in Figure 10.

Figure 2 is a schematic representation of the deployable structure 100 in a partially folded state. The deployable structure 100 is folded from the fully deployed state by detaching the central element 130 from the upper hinge 108.This may be done by various means, for example, by releasing the fastening mechanism (not shown) on the upper hinge 108. Where the central element 130 is in the form of a telescopic element, the length of the central element 130 may be reduced during detachment of the central element 130 from the upper hinge 108. When the detachable end of the central element 130 is disconnected from the upper hinge 108, the elements 140, 150 are folded towards the central member.

By exploiting the flexibility of the cables or flexible members 170 to improve the foldability of the deployable structure 100, improved compaction of the structure 100 can be achieved, when the structure 100 is folded. Further, the use of the cables or flexible members 170 make the deployable structure 100 significantly lighter and stiffer, compared to conventional designs. The mechanical complexity of the structure is also minimised. The cables 170 also carry tensional loads efficiently and help to stabilise the geometry of the deployable structure 100. Furthermore, a wide variety of structural shapes may be created by varying the length of the cables 170. The cables 170 may be metallic or composite materials cables, fiber-based cables, etc.

A plurality of deployable structures may be connected and deployed to form structural systems. For example, a plurality of the deployable structures 300 may be connected in-line to form a beam 301, as shown in Figure 3a. A cable or 390 may be used to join the lower hinge 304 of each deployable structure 300 to form the beam 301. The middle hinges e.g. 307 may be of an integral type between adjacent individual structures 300, i.e. one middle hinge e.g. 307 may be "shared" between adjacent individual structures 300.

In another example embodiment, a plurality of the deployable structures 350 may be connected in-line to form a beam 302, as shown in Figure 3b. A cable 391 may be used to connect the upper hinges 306, in addition to the cable 391 joining the lower hinges 305.

Alternatively, a plurality of deployable structures 400 may be connected and deployed in an array to form space frames and vaults, as shown in Figure 4a. Similarly, connecting cables 490 may be used to join the lower hinges 404 of each of the deployable structures 400. Further, a combination of beam and space frame structures can also be synthesized using variations of the deployable structure 400. For example, a barrel vault configuration can be created by changing the lengths of the connecting cables 491 joining the lower elements 406, as shown in Figure 4b.

Figure 4c illustrates another example embodiment with additional connecting cables 493 connecting the upper elements 407. It should be appreciated that the connecting cables 490, 493, may be in other forms, for example, elements. Figures 4b and 4c show only one row of connected deployable structures. However, it should be appreciated that the length of the connecting cables 490 joining the array of deployable structures 400 (shown in Figure 4a) may be changed to achieve similar configurations shown in Figures 4b and 4c. Other shapes, for example, a dome, can also be created by using a combination of hexagonal, pentagonal, triangular and other structural shapes.

Referring to Figure 5, the deployable structure 500 may be divided into three planes – a first plane (lower plane) 510 comprising the lower hinge 504, a second plane (upper plane) 520 comprising the upper hinge 508 and a third plane (middle plane) 530, between the lower plane 510 and the upper plane 520, comprising by the middle hinges 512. In this example embodiment, a network of cables (not shown), a membrane or sheet , etc may be attached to the upper and/or middle and/or lower planes 510, 520, 530 respectively to form various types of structural systems. It should be appreciated that a plurality of planes may be provided between the lower and upper planes 510, 520.

Alternative embodiments of the deployable structure are shown in Figures 6 to 10.

Vertical rods 620 , shown in Figure 6, may be attached to the middle hinges 612 of the deployable structure 600 to facilitate attachment of sheets of fabric material or to increase the depth of the structural unit, or for bracing and other purposes.

Other types of connecting attachments may be added to the hinges to enable the attachment to other structural units or sheets or fabric material. Figure 7 shows a schematic representation of the deployable structure 700 according to another example embodiment. The deployable structure 700 has two layers of middle hinges comprising upper middle hinges 712 and lower middle hinges 714. A vertical member 765 connects each of the upper middle hinges 712 to a corresponding lower middle hinge 714, defining a parallelepiped..

Alternatively, other forms of deployable structural units (e.g. 895) may be disposed between an upper middle plane 862 and a lower middle plane 864 of the deployable structure 800, as shown in Figure 8, to increase the depth of the deployable structure 800, improve structural efficiency and to facilitate deployment of the structure 800. In this example, the additional structural units 895 comprise a pair of rods 896, 897 pivoted to each other substantially in the centre.

In another example embodiment, the deployable structure 900 may comprise cables 970 connecting the middle hinges 912 diagonally, as shown in Figure 9. The deployable structure 900 may also have additional cables connecting the middle hinges 912 (compare the cables 170 in Figure 1).

It will be appreciated by a person skilled in the art that numerous variations and/or modifications may be made to the present invention as shown in the specific embodiments without departing from the spirit or scope of the invention as broadly described. The present embodiments are, therefore, to be considered in all respects to be illustrative and not restrictive.

For example, the central element may have energy stored devices such as springs, that help in the deployment process. Various telescopic and cable-realized mechanisms may be used to assist the coordinated deployment of the structure. Springs may be incorporated into the hinges for the same purpose. The cables may also be spring loaded or may have elastic attachments to prevent entanglement during deployment of the structure.

The elements may be telescopic or telescopic and lockable to provide flexibility in configuring the structure.

Further, the deployable structures may be combined with structural kinematic chains to facilitate deployment.

The cables and/or the elements may be pre-tensioned to enhance the structural behavior of the unit.

Fabric, sheet and other forms of covering material may be attached to the rods or cables by introducing additional connectors or by designing their shape to facilitate direct attachment.

By using cables that fold and attachable members (e.g. struts) that do not constrain the design, the example embodiments described above allow the fully deployed state of the structure to be structurally optimal.

The structures in the example embodiments achieve quick installation with the minimal assembly operations. The structure is substantially free of stress during deployment and in the folded configuration.

Possible industrial applications of the deployable structures include a wide range of temporary and permanent structures such as exhibition, emergency, entertainment, military, and space structures that require rapid deployment. It also can be used for shelters, roofs, bridges, pylons, radars, vaults and structures of various configurations.